# Chapter 4
# Borrow Areas and Quarries

*Section I*
*Earth Fill*

## 4-1. Excavation, Handling, and Hauling Equipment

Over the past several decades, significant improvements in earth-moving equipment have been made at an increasing rate, and there is no indication that this trend will slow. While the basic types of equipment have remained virtually the same, speed, power, and capacity have continuously increased. Some of the basic principles of the more common units are discussed in the following paragraphs.

*a. Excavation equipment.*

(1) Power shovels, draglines, elevating graders, wheel excavators, and scrapers. Excavation is usually accomplished with power shovels, draglines, scrapers, wheel excavators, or side-delivery loaders. Each offers certain advantages and has certain disadvantages; therefore, several types are often used on the same job. Discussion of the four major types of excavation units is given in Figures 4-1 through 4-3.

(2) Dredges. Dredging is sometimes employed to move material from borrow areas to the damsite. Dredges are particularly suitable for use when large quantities of material are to be obtained from borrow areas submerged in rivers, lakes, etc. The two basic types of dredges are the bucket dredge and the hydraulic dredge.

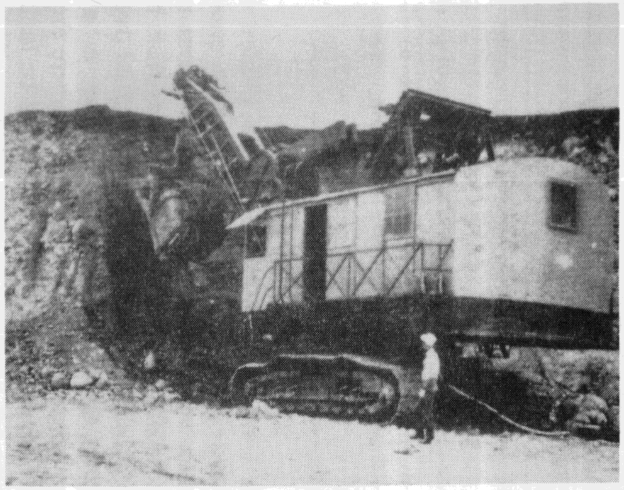
(a) Bucket dredge. A limiting disadvantage of bucket dredges is that the discharge is alongside the place of excavation. They can best be used for localized dredging or where the borrow area is located so that the material can be economically transported by trucks or barges to the site. There are three types of bucket dredges: grab dredges, dipper dredges, and ladder dredges. The grab dredge is essentially a grab bucket operated from a derrick mounted on a flat-topped barge. The dipper dredge is simply a power shovel operating from a barge. The ladder dredge excavates with a continuous chain of buckets supported on an inclined ladder. Bucket dredges have the advantage that they can excavate in most any material. Dredging depths greater than 100 ft are not uncommon for grab dredges. Digging depths of the dipper dredge are limited by the length of the boom (65 ft is about the maximum, although greater lengths are available for special projects) while the digging depth of the ladder dredge is limited by the length of the ladder (usually around 40 ft, but lengths greater than 75 ft are not uncommon).

(b) Hydraulic dredges. All hydraulic dredges basically consist of a centrifugal pump and a suction line through which the pump is supplied with material, but different means are used to loosen and pick up material. Hydraulic dredges can transport material without rehandling for practically unlimited distance if booster pumps are used; this feature is particularly useful in the construction of temporary dikes and permanent structures by the hydraulic fill method. However, it must be mentioned that material placed by the hydraulic fill method will be loose, essentially water-saturated, and probably susceptible to liquefaction if sufficiently disturbed by the mechanisms specified in paragraph 3-4*a*(4). The most common dredge in current use is the cutterhead dredge, which excavates material with a rotating cutterhead then removes it by suction. The cutter is attached to the forward end of a ladder or to the suction pipe itself; rotation of the cutter agitates soft material and/or cuts hard material. Various types of cutters are available, and the type to be used depends on the hardness of the material to be excavated. Some cutters can cut into sound rock. The maximum suction available at the pump is about 28 ft of water; therefore, head losses must be kept to a minimum in order to provide adequate suction.

*b. Hauling, handling, and separating equipment.* Borrow material excavated by scrapers or by dredging is usually taken directly to its point of deposition on the embankment under construction. However, when most other excavation procedures and equipment are used, additional hauling and handling are required. Regardless of the equipment used, borrow material may require sorting and/or separation according to size or material type. Some of the equipment used for hauling, handling, and separating borrow materials is discussed in the following paragraphs.

(1) Trucks. Trucks of many types are used to transport embankment material from the borrow pit to the dam, capacities of up to 50 tons being common. They can be categorized according to method of unloading as bottom dump, end dump, or side dump.

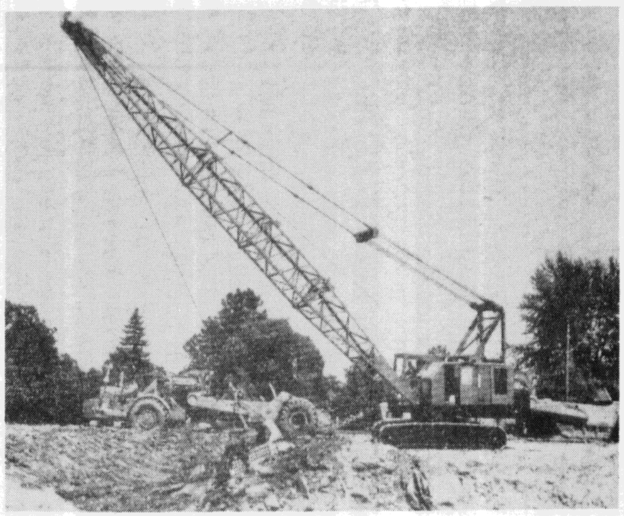
(2) Belt conveyors. Belt conveyors (Figure 4-4) are used to transport material from the borrow area to the damsite when very large quantities of material must be moved under difficult conditions. Belt conveyors are most suitable for moving large quantities of material over rough terrain where there are large differences in elevation between the borrow pit and the dam, and where the cost of building and maintaining haul roads would be high. Conveyor systems are adaptable to different types of automated processing procedures: screening plants, crushing plants,



Courtesy of Koehring, Milwaukee, Wisconsin

**POWER SHOVEL**

| | |
|---|---|
| Primary Use: | Excavation above working level |
| Advantages: | Very versatile for mixing layered materials during excavation; can excavate much harder materials than can a dragline |
| Disadvantages: | Fairly accurate truck spotting required when loading; excavates hard materials in large chunks that must be broken prior to compaction |
| Capacities: | Common bucket capacities are 4 to 14 cu yd although larger capacities are not uncommon; typical rates of excavation for average construction conditions range between 70 and 90 cu yd/hr per cu yd of bucket capacity |

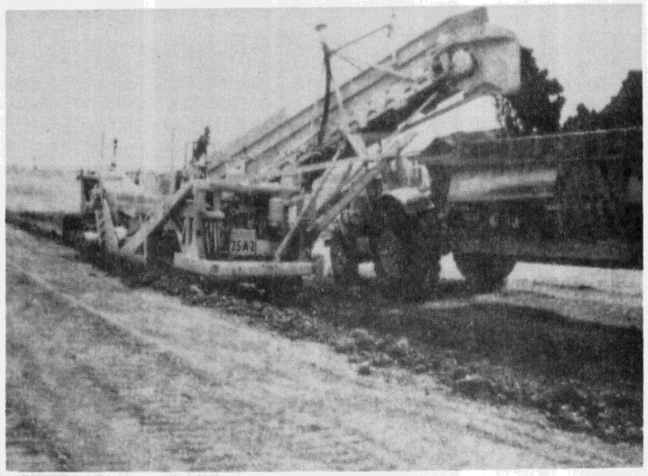


Courtesy of Koehring, Milwaukee, Wisconsin

**DRAGLINE**

| | |
|---|---|
| Primary Use: | Excavation below working level |
| Advantages: | Especially effective in excavating pervious materials from below water table; effective where borrow pit bottom is too soft to support trucks or scrapers |
| Disadvantages: | Generally slower than shovels and scrapers; cannot excavate hard materials; not as efficient as power shovel in mixing layered material in borrow pit |
| Capacities: | Bucket capacity frequently about same as that of power shovel, although some draglines are used with buckets much larger than those usually used on shovels |

**Figure 4-1. Power shovel and dragline**



Courtesy of Barber-Greene, Aurora, Illinois

**ELEVATING GRADER**

| | |
|---|---|
| Primary Use: | Excavation in large, flat areas of uniform material with direct discharge into hauling equipment |
| Advantages: | When the borrow areas are large with flat topography and uniform soil conditions, side delivery loaders generally provide the most economical and rapid means of excavation |
| Disadvantages: | Not particularly efficient in borrow pits containing cobbles and sands |
| Capacities: | Normal cut 3 to 4 ft deep and common production rates between 800 and 1,200 cu yd/hr |

Courtesy of Barber-Greene, Aurora, Illinois

**WHEEL EXCAVATOR**

| | |
|---|---|
| Primary Use: | Excavation in large areas of reasonably uniform topography and material, with direct discharge into hauling equipment |
| Advantages: | High volume of excavation; exceptionally good blending of material; good conditioning of material; can work in granular materials, materials containing cobbles, and materials with some cementation |
| Disadvantages: | Borrow areas must have reasonably flat and uniform topography; slow travel speed to other areas; if unit breaks down, all borrow operations cease |
| Capacities: | Face cut up to 10 ft wide and 13 ft deep; 1,750 nominal bank yd/hr capacity |

Figure 4-2. Elevating grader and wheel excavator

**SCRAPER**

| | |
|---|---|
| Primary Use: | Excavation in uniform material or where it is desired to excavate horizontally stratified deposits selectively |
| Advantages: | Serve as both excavating and hauling units; larger and faster units can compete with trucks as hauling units; deposit borrow material in even layers, sometimes eliminating use of additional spreading equipment; borrow material is broken up when excavated, making compaction easier. |
| Disadvantages: | Unsatisfactory for use in very soft materials; pusher tractor sometimes required when loading |
| Capacities: | Capacities of 30 cu yd are common |

Note: Self-propelled rubber-tired scrapers are rapid-moving type; scrapers towed by slower moving crawler tractors may be preferred where better traction is needed in the pit and the haul is relatively short.

Figure 4-3. Scraper

blending operations, water additions, etc. Transfer points (where the material is transferred from one belt to another) are usually required. Automatic facilities for loading trucks at the terminal points can be easily provided, or sometimes the material can be dumped directly from the belt onto the embankment, spread with bulldozers or grader, and compacted.

(3) Separation plants. Separation or screening plants (Figure 4-5) are employed where it is desired to separate different particle sizes of a granular material. Generally, the purpose is to remove oversize rocks or cobbles to facilitate compaction or to remove fines from filter material. There are four principal types of screening plants:

(a) Horizontal or sloping stationary screens. With this equipment, material is directed through a stack of stationary screens/sieves with screen opening sizes decreasing toward the bottom of the stack. Larger soil particles are retained on the upper screens while smaller particles fall through to be retained on a lower screen.

(b) Vibrating screens. This equipment is basically like the stationary system described above except that soil separation through the screens is facilitated and expedited by vibrating the screens.

(c) Rotating trommels. This equipment consists of an inclined rotating cylinder with screens or holes of different sizes around the periphery. Separation is accomplished when soil particles of different sizes fall through the appropriate hole size as the mixed material rolls around inside the rotating cylinder.

(d) Wobblers (or rotating cams). In wobblers, rotating cams produce vibrations which cause fines to fall through sloping screens, whereas the larger (rock) particles tumble down the sloped screens and fall over the edge onto a pile or a conveyer belt. Each type of separator is discussed in more detail in paragraph 4-4*c*. Various plants have capacities ranging from 100 to 2,000 cu yd/hr, but most plants process 300 to 500 cu yd/hr. Wet materials having appreciable clay content are the most difficult to process, since the clay tends to clog the screen openings.

## 4-2. Borrow Area Operation

*a. Plans for development.* The contractor should be required to submit detailed plans prior to construction for the development of borrow areas and quarries. These plans should be carefully reviewed prior to approval and rigidly followed during construction.

*b. Inspection.* Inspection of borrow pits includes observing and recording all earthwork operations performed in the borrow pit prior to dumping the material on the embankment. Working under the supervision of the construction engineer and chief inspector, the borrow pit inspector observes areas excavated, depth of cut, and adequacy of the contractor's equipment for the tasks at hand. Inspectors should inform the chief inspector of conditions that deviate from the plans and specifications, so that corrective action can be taken if necessary; these deviations include:

(1) Borrow materials that are different from those expected to be obtained in the borrow area.

(2) Borrow excavation operations that are not producing the desired blend or type of material required.

(3) Borrow materials that are too wet for proper

**Figure 4-4. Belt conveyor system**

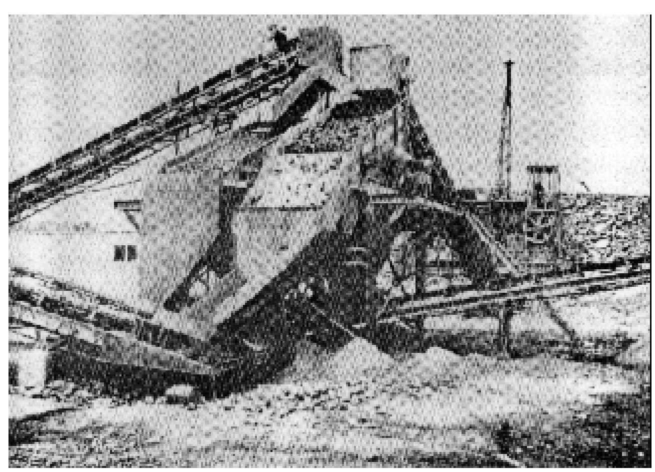


**Figure 4-5. Vibrating screen separating plant**

compaction. During excavation and processing, the inspector observes all adjustments made to the water content of the material. If separation or blending is required, the inspector performs tests to ensure that the soil type and/or gradation of the processed material meets the specifications.

*c. Water content control.* Water content changes occur in borrow pits because of rain, evaporation, or the addition of water for the direct purpose of raising the borrow material water content. Earthwork contractors should be encouraged to take steps to hold the water content of the excavated borrow material as close to the desired placement water content as possible prior to delivery to the embankment.

(1) Dry soils.

(a) For most clays it is not desirable to add more than 3 to 4 percent water on the fill, and in arid regions the average natural water content of soils in borrow areas may be 10 to 15 percent below the desired value for compaction. Under such conditions, irrigation of borrow areas generally results in more uniform water content distribution, while also being the most economical method of adding water. Borrow areas are frequently wetted to depths of 5 to 15 ft or more by surface irrigation.

(b) The water content of soils in a borrow area may be increased by constructing low dikes and ponding/flooding the area or with a pressure sprinkling system. Controlled ponding/flooding is most suitable in low-lying flat areas and tight soils for which long wetting periods are needed. Sprinkling is advantageous on sloping ground and in large borrow areas where only relatively shallow wetting is needed. It is desirable in some borrow areas not to strip topsoil before ponding/flooding, since stripping tends to seal natural holes and cracks in the ground surface which facilitate the entry of water. Ripping tight surface layers has been found effective in speeding up the wetting process. When sprinkling is used on hillside/sloped borrow, it may be desirable to use contour plowing to prevent surface runoff. Good judgment should be used in prewetting steep hillside borrow so that slides are not induced. The length of time required for wetting/hydration may vary from a few days to several months, depending on soil permeability and the depth to which moistening is desired. A curing period is desirable after wetting to allow added water to be absorbed uniformly by the soil. The time needed and the best technique to use can be determined by experimentation.

(c) If general borrow pit irrigation is not satisfactory, supplemental water can be added by sprinkling the face of a shovel excavation; the water is mixed into the matrix as the material is shoveled, hauled, dumped, and spread. If soil is being processed through a screening plant to remove oversize cobbles, a considerable amount of water can be blended into the soil by sprinkling within the plant.

(2) Wet soils.

(a) It is generally easier to add water to dry soil than to reduce the water content of wet soil. The difficulty of lowering the water content of a soil deposit will depend on the plasticity of the deposit and on the amount and type of rainfall during construction. The rainfall pattern is important; for example, a few scattered cloudbursts are less harmful than the same amount of precipitation falling as rain over a longer period of time. It is practically impossible to dry out borrow material to any extent without excessive work and cost unless a dry season of sufficient length permits evaporative water loss.

(b) The first step in either drying out or maintaining the in situ water content of borrow material is to provide surface drainage in the borrow area; this is done by cutting ditches and sloping surfaces to drain to these ditches. Since water is drained away from the borrow material, absorption of subsequent rainfall is minimized. Wet soil can sometimes be dried by ripping, plowing, disking, or otherwise aerating the soil to a depth of several inches. The time required for drying (and hence the production of usable material) will depend on soil plasticity, the depth to which the material can be aerated, and climatic conditions. After the soil has dried to a usable water content, it may be removed with elevating scrapers or graders and the process of aeration, drying, and removal repeated. The procedure described is relatively effective for silty and sandy soils, but is not effective for plastic clays; if the water content of plastic clays is lowered by aeration in dry climates, the result may be hard dry chunks which are difficult to process. Open ditches in borrow areas of sandy and silty soils with a high water table will drain off excess water and lower the water table.

(c) In the construction of Dorena Dam, Oregon, by the Portland district, disking the borrow areas did not break up and mix the clay material enough to obtain uniform water content distribution within the soil. This problem was solved by using a heavy rotary pulverizer pulled by a crawler tractor after the disking. Shortly after pulverizing, the material was at or near placement water content, was easy to load, and was in excellent condition for compaction.

(d) In very wet climates and adverse weather conditions, it may only be possible to prevent borrow material from becoming wetter during construction. This may be accomplished by such techniques as providing surface drainage and/or using equipment that minimizes the chance for material to absorb additional water. Excavating with power shovels on a vertical face is an example of this strategy.

*d. Blending soil layers with excavating equipment.*

(1) Blending two or more soil types may be required where different soil strata are present in borrow areas or required excavation. Reasons for blending soils are to obtain borrow materials having acceptable characteristics for a particular embankment zone and to utilize borrow materials so stratified in situ that it would not be feasible to load and place material from individual soil strata.

(2) Where materials to be blended occur as horizontal strata, shovels, draglines, wheel excavators, or in some cases, scrapers have been used to blend them during excavation. Excavation with a power shovel on a vertical cut will blend the materials. Where more extensive mixing is required, it can be achieved by running the open bucket through the mixture several times before loading. Construction control in this case will require maintaining the height of cut necessary to obtain the desired proportions of each type of material and to ensure that the materials are blended thoroughly.

(3) Blending different materials from different sources can be accomplished by stockpiling one layer on the other so that excavation can be made through the two materials as in a stratified natural deposit. However, this procedure is expensive and is seldom used.

(4) Scrapers have been used to mix stratified deposits by developing the excavation in such a way that the scraper is loaded on an incline, cutting across several horizontal strata of different materials; however, this procedure is generally not as effective in mixing as the use of a shovel, dragline, or wheel excavator.

*e. Selection of materials intended for different embankment zones.*

(1) The borrow pit inspector must assure that materials intended for a certain embankment zone are within specification limits. Selection of materials will, to a large extent, have been accomplished on the basis of design studies; that is, borrow areas for the various zones will have been designated. Design studies should have disclosed the nature of the materials and the expected ranges of variation. Therefore, field personnel should review the results of all investigations and know what materials are acceptable; the inspector must be able to identify these materials visually as far as possible, and with a minimum of index tests.

(2) The use of proper equipment by the contractor will also aid in preventing undesirable mixing of soil types. For instance, stratified deposits of distinct soil types to be kept separate should be excavated with a scraper since scrapers excavate by cutting relatively thin strips of soil, thereby avoiding mixing of strata. Screening plants are sometimes employed to obtain required gradations. Although screening of natural materials for major embankment volumes is an expensive process, it may not be excessively so when compared with the benefits. The use of screening plants may avoid major placement problems, allow steeper embankment slopes, and employ a lesser volume of material. Screening is used most often in connection with filter materials.

(3) If any materials are encountered in borrow areas having characteristics that differ appreciably from those anticipated, such materials should not be used unless approved by the design office.

(4) The borrow pit inspector must ensure that materials of possible short supply are conserved.

*f. Oversized materials.* The maximum diameter of stone or cobble allowed in compacted fill is generally limited to about three-fourths the thickness of the compacted layer. Where a high percentage of oversized cobbles or stones is present, oversize material removed may be used in the outer portions of the dam. Oversize materials can be removed on the fill surface by hand labor or by special rakes mounted on tractors, or they can be screened out in the borrow areas. Generally, removal of oversized rock is more efficiently accomplished in the borrow areas. Rock separation plants are usually employed for this purpose. Processing methods are discussed further in paragraph 4-4*c*.

*g. Stockpiling.* When excavation of fill material from borrow sources progresses at a faster rate than its placement in the embankment, the material can be stockpiled near locations where it is to be used. Stockpiling involves expensive rehandling and is generally only used on large projects where borrow is to be used from an excavation made before embankment construction, where borrow areas will be flooded during construction, or when material must be stockpiled close to its point of intended placement for rapid construction of a closure section. Unless stockpiling is a specified item, its use is at the expense of the contractor. Stockpiling is advantageous in cases where borrow must be transported long distances and moved by conveyor belt or other means at the site. Filter materials are often stockpiled when it is necessary to obtain them from commercial sources or to manufacture them on the site. Care should be taken in stockpiling filter materials to avoid segregation, contamination, and particle breakage. In dumping filter material onto a stockpile, drop heights should be kept at a minimum; the filter material stockpile should be located well away from other types of material, the area should be sloped so that water drains away from filter stockpiles, and heavy equipment should not be operated over filter materials. Gradation tests should be performed on samples of filter material from a number of locations around the stockpile before and after it is placed to ensure that specifications have been met. The advantages of maintaining stockpile quality should be well understood and appreciated by site personnel, especially if many contractors will use the stockpile.

*h. Cold weather operations.* Borrow area operations can often continue into freezing weather without loss of embankment fill quality. Frost penetration progresses slowly in undisturbed (in situ) fine-grained soils except in extremely cold weather, and soils will generally remain unfrozen if borrow operations are conducted continuously. Material satisfactory for fill placement can be obtained if the in situ water contents do not require adjustment on the fill. Sands and gravel can generally be excavated and handled effectively under very low temperatures, but the addition of water on the fill for compaction may present problems. Borrow excavation in cold weather is usually limited by fill placement requirements; it should be limited to use only in special situations and should be practiced with considerable caution.

*Section II*
*Quarries and Rock Excavation*

## 4-3. General

Even experienced geologists and engineers often cannot predict how rock obtained from a quarry or excavation will break down after blasting. Consequently, field personnel must be particularly observant of the contractor's methods and the results obtained. The most frequent trouble occurs when the quarried material either contains more quarry fines and dust or more oversized material than had been anticipated in the design. It has sometimes been necessary to make major design changes because rock behavior or breakdown was contrary to that anticipated by the designers. See EM 1110-2-3800 for further guidance on the subject.

## 4-4. Equipment

*a. Loading.*

(1) Power shovels and front-end loaders are used almost exclusively today for loading trucks or other vehicles in rock excavations or quarries. Power shovels have been used for many years; large front-end loaders have recently come into prominence with the advent of more powerful units with large capacity buckets. In a deep quarry, the walls and face must be carefully scaled as rubbelized material from a blast is cleaned up to prevent rockfall accidents.

(2) The power shovel, either electric or diesel, is still the most common piece of equipment for loading directly from the muck pile, although front-end loaders have been used in this capacity also. The power shovel is generally desired because of its large capacity, its powerful bite, and its efficiency in getting the load from the bucket to the carrier.

(3) Front-end loaders are used most often to load processed material from stockpiles. A front-end loader may be either tracked (crawler) or rubber-tired. The crawler type has been used often in the past, but the four-wheel-drive rubber-tired type has recently become popular. Although the rubber-tired loader lacks the traction of the crawler, it is faster and usually has sufficient traction on most surfaces to load a full bucket efficiently.

*b. Hauling.* Trucks are generally used as prime movers of rock fill. The three basic truck types are the end dump, the bottom dump, and the side dump. Side dumps are rarely used for the construction of compacted rock-fill dams; they are more useful for building out the edges of fills. Bottom dumps are more frequently used, but they have definite limitations; they are somewhat unwieldy, and oversize rock has a tendency to become trapped in their discharge gates, requiring bulldozers to push them off the rock and thus costing time and disrupting the hauling schedule. At the Lewis Smith Dam, Alabama, all bottom dumps had to be taken off the job and replaced with end dumps for this reason. End dump trucks are probably the most frequently used vehicles for rock hauling because of their speed, mobility, and generally lower first costs to the contractor. End dumps vary in size from the light "dump truck" to semitrailer types with capacities in excess of 100 cu yd. Since in most cases hauling from rock excavations and quarries is "off-the-road" hauling, these trucks are not subject to size and weight limitations imposed upon carriers that travel on public highways, thus allowing the large capacities.

*c. Processing.* It is usually necessary to process fragmented rock produced by blasting since it is unlikely that the required sizes and/or gradation would occur directly from blasting. Processing may involve removal of oversize or undersize (fines) material, or obtaining a specific size range for use in a particular zone of the embankment such as a graded filter. Preparations should be made to stockpile filter material when it is convenient to prepare the proper gradation; this ensures an adequate supply of filter material during rainy periods when the screens of a processing plant tend to clog. There are several types of separation or processing plants, each with its own advantages and disadvantages; the use and end product desired will dictate the choice of plant. Some of the more common plants are briefly discussed below.

(1) Grizzlies. The grizzly is perhaps the most common separating device; it is used only for removing oversize rock from the material which, in some cases, is all that is needed to obtain the gradation specified. A grizzly consists of a sloped grate made of heavy bars which are wider at the top than at the bottom to ensure that particles do not bind partway through the gratings and clog the openings between the bars. Grizzlies are often constructed with sloped vibrating screens or with rotating cams (grizzly wobblers) so that oversize material passes over the grate and falls off the end while the desired material falls through the grate. Grizzlies may be constructed in many ways, but they always involve the use of a grate or lattice of heavy bars. Figure 4-6 shows a sloping grizzly in operation at Gathright Dam, Virginia. A grizzly wobbler used at Stockton Lake Dam, Missouri, is shown in Figure 4-7.

(2) Trommel. A trommel is a separating device which consists of a rotating cylinder of perforated sheet metal or wire screen. Like the grizzly, it is used for eliminating oversize particles, but it can also separate the remaining material into various size fractions. A trommel can be open at either one end or both ends with the axis of the cylinder horizontal or slightly inclined so that the material is advanced by rotation of the cylinder. Size of the perforations in the sheet metal or of the openings in the screen can be varied to obtain more than one size fraction. As material is fed into the rotating cylinder, the oversize material passes through and is discharged at the other end, while each of the fractional sizes falls through a properly sized opening into hoppers or onto conveyor belts which transport the various sizes to stockpiles.

(3) Shaking or vibrating screen. This device is generally used for sizing. It consists of a metal screen or multiple screens with desired opening sizes, mounted either horizontally or inclined on a rigid frame and given either a reciprocating motion (in the case of a shaking screen) or a vibrating motion (in the case of a vibrating screen). A vibrating screen separating plant is shown in Figure 4-5. Material retained on a given screen passes on to one end of the screen, where it is discharged into a hopper or onto a belt. More than one size can be separated by having screens of successively smaller openings below the initial screen.

## 4-5. Test Quarries

*a.* Test quarries aid the designer in determining the sizes, shapes, and gradations of rock produced by excavation and handling. Test quarries are usually operated in conjunction with a test fill so that all aspects of rock behavior from blasting to compaction can be evaluated. Variables in quarrying operations include drilling, blasting techniques, loading, processing, and hauling procedures and equipment. A properly executed test quarry program will provide the designers and field personnel valuable information pertinent to cut slope design, evaluation and control of geologic structures, best blasting technique, and rock fragmentation control to be used; provide representative materials for test fills; give prospective bidders a better understanding of the drilling and blasting behavior of the rock; and determine what processing, if any, of the rock will be required. A test

**Figure 4-6. Rock separation by means of a sloping bar (grizzly) arrangement at Gathright Dam, Virginia**

**Figure 4-7. Grizzly wobbler discharging +2-in. rock into end-dump truck and -2-in. material into bottom-dump truck (spillway-powerhouse excavation at Stockton Lake Dam, Missouri)**

quarry in operation at Foster Dam, Oregon, is shown in Figure 4-8.

**Figure 4-8. Test quarry in operation at Foster Dam, Oregon**

*b.* Even though test quarries are usually established during design, contracts are frequently administered by the construction division, working in cooperation with the design engineers. It is desirable that construction personnel assigned to the test quarry be later assigned to the dam construction, if possible. These personnel will have gained valuable insight into construction procedures and material behavior and would form an important nucleus when staffing for dam construction.

*c.* The purpose of construction control is primarily to ensure that different test methods and procedures called for in the plans and specifications for a test quarry are followed so that comparison of different methods and analysis of data acquired will be meaningful. It is important that complete and accurate records are kept throughout the job. Records should include types of drilling equipment used; rates of drilling in each type of rock; hole diameter, depth and spacing; explosive type, charge, and spacing; stemming material and procedure; time sequence of firing; and details of results obtained by blasting.

## 4-6. Obtaining Specified Rock Fill

The specifications will prescribe the gradations of the rock fill to be placed in the various zones. It may be possible to obtain acceptable material directly from blasting, but the rock may have to be processed in one form or another. In any case, the inspector must ensure that the placed rock meets the criteria set forth in the plans and specifications. The contractor's method of operation has a significant effect on the gradation of rock obtained. Therefore, the inspector should be familiar with methods of operation that affect the rock fill.

*a. Drilling and blasting.*

(1) It would be very desirable and economical to obtain the required gradation directly from the piles of blasted rock, but this is generally difficult and some experimentation by the contractor will be necessary. Preliminary experimental shots should provide criteria for establishing satisfactory drilling and blasting patterns. The spacing of boreholes and intensity of charge required will depend on in situ rock conditions. See EM 1110-2-3800 for information required from contractors and for guidance on approving blasting procedures and inspecting blasted areas.

(2) Rock is excavated or quarried either by the "bench method" using vertical holes, or by "coyote holing," which involves firing large explosive charges placed in tunnels driven into a rock face at floor level. Coyote holing is initially cheaper than the bench method, but frequently results in excess fines and oversize stones that require secondary blasting. As a general rule, the coyote method should not be used when quarrying for rock-fill structures.

(3) In quarry experimentation, the material broken by the first blast should be cleared away not only to determine if the correct gradation has been achieved, but to examine the excavation rock face and the condition of the excavation floor. The power shovel has been mentioned above as the best means of loading/moving blasted rock in quantity, but it must be operated from a relatively level floor.

(4) In a normal shot, the coarser material will be located away from the face and on the top; the finer materials will be concentrated toward the working face and at the bottom. The operator of the loading equipment should be cautioned and instructed on loading procedures that will help ensure a uniform distribution of sizes in each load if the rock is used without processing. In many quarries, a layer of fines will become concentrated on the quarry floor as loading progresses and must be either used elsewhere or wasted.

*b. Processing.* If the contractor cannot obtain the correct rock sizes by blasting or if special treatment is called for in the specifications, processing will be required. The degree of processing will vary from using a simple grizzly to remove oversize rocks, or washing to remove excess fines, to running material through a crusher plant. Rock crusher plants are not generally used for processing rock fill due to high operational cost. However, crusher plants are sometimes used to produce select filter materials such as transition or bedding material. The amount of processing required will depend on the results of the blasting unless special processing is expressly called for in the specifications. Different types of separation equipment and their utilization have been described above.

*Section III*
*Final Condition of Borrow Areas, Quarries, and Spoil Areas*

## 4-7. Borrow Areas

Generally, no treatment is required for reservoir-side borrow areas located below minimum operating pool elevation. However, for reservoir-side borrow areas located above this elevation and land-side borrow areas, some treatment is generally required to eliminate what would otherwise be unsightly scars. Treatment of these borrow areas usually begins with the contractor stockpiling topsoil when first opening the borrow pit. After all usable borrow has been removed (the contractor should not be allowed to excavate to bedrock, but should be required to leave a foot or two of soil over rock), the previously stockpiled topsoil should be spread back over the borrow area and graded to a smooth, uniform surface, sloped to drain. On steep slopes, benches or terraces may have to be specified to help control erosion. As a final step, the entire area should be fertilized and seeded. These procedures are intended to prevent erosion and bring the borrow area to a pleasing aesthetic appearance and possibly make it available for future use.

## 4-8. Quarries

Abandoned quarries are unsightly and may be a safety hazard. As far as practicable, old quarries should be drained and provisions made to prevent any further ponding of water in them. All slopes should be scales and trimmed to eliminate the probability of falling rocks and debris. All areas that can support vegetation should be seeded. In some cases, fencing may be needed to restrict free access.

## 4-9. Spoil or Waste Areas

Specific areas must be provided for the disposal of waste or spoil materials. These areas should be clearly shown on specification drawings. Material which is unsuitable for other purposes is usually used to fill and shape depressions such as ditches, sloughs, etc., located outside the limits of the embankment. Waste material in excess of that required to fill these depressions may be used upstream to reinforce seepage blankets or used as berms to add to the stability of the structure. Waste areas located downstream of the embankment must be carefully selected to avoid interference with any component of the structure or creation of undesirable areas requiring excessive maintenance or remedial work. Waste materials should never be permitted to block seepage from drains, pervious zones, or rock toes. Additionally, disposal areas should not be located such that they could possibly cause contamination of natural groundwater. Generally, no compaction of material in waste areas is needed other than that produced by hauling equipment except on the finished outside slopes. Surfaces should be left reasonably smooth and sloped to provide drainage away from the embankment and construction activities. Outside slopes of waste areas composed of easily erodible materials should be compacted or track-walked to prevent erosion. If possible, the areas should be fertilized and seeded to improve their appearance and prevent erosion, thus possibly making them suitable for recreational purposes.